CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-245

SILVER STRAND FAULT, CORONADO FAULT, SPANISH BIGHT FAULT, SAN DIEGO FAULT and DOWNTOWN GRABEN

Southern Rose Canyon Fault Zone

San Diego, California

by

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INTRODUCTION

The Rose Canyon fault zone is the southern member of the Newport-Inglewood – Rose Canyon fault zone, a major strike-slip fault zone and a member of the San Andreas fault system (Figure 1). In the San Diego area, on the Point Loma 7.5-minute quadrangle, this fault zone splays out to the south as a number of strands. The Silver Strand, Coronado and Spanish Bight faults (Figure 2) trend southerly and have been mostly defined by geophysical techniques within San Diego Bay and offshore to the south (Kennedy and Welday, 1980; also Kennedy and others, 1977). The San Diego fault (Figures 2 & 3) is within the downtown San Diego area (Treiman, 1993), and was discussed in a previous Fault Evaluation Report (FER) for the on-land portion of the Rose Canyon fault zone (Treiman, 1991). At the time of that evaluation a young graben was identified and zoned within the downtown area but there was insufficient evidence to classify the San Diego fault as Holocene active. However, recent investigations have provided evidence that the San Diego fault as well as some of the other southern splays of the Rose Canyon fault zone are active. The purpose of the present FER is to document the data pertaining to the location and activity of these faults, and to determine whether they meet the criteria for zoning under the Alquist-Priolo Earthquake Fault Zoning Act (Hart and Bryant, 1997). Other FERs for the Rose Canyon and related faults include the work of Kahle (1988) and Saul (1979a,b,c).

PREVIOUS WORK

San Diego fault (Figure 4)

Early geotechnical studies suggested that the Coronado fault may project through the southwestern downtown area (Leighton, 1978). Subsequent exploration for Horton Plaza (initially a 15 city block redevelopment project), using stratigraphic correlation between borings, identified an inferred fault (down to the east) in the block south of Broadway and east of Front Street (Leighton, 1979, see Figure 4). This fault, based on elevation differences and thickness changes of subsurface horizons (including a late-Pleistocene beach sand), was considered a possible northward projection of the Coronado fault, although the report acknowledged that the strike of the inferred fault was uncertain. Leighton (1979) also commented on the possibility that the inferred fault may be related to a southeast-trending drainage (also discussed later, see Figure 10). Another redevelopment study (Crandall, 1980) found evidence of three structural anomalies to the south, based on a line of borings along G Street. These borings and anomalies are indicated on Figure 4. The western anomaly was marked by a distinct lithologic break and was interpreted at that time to be the northern projection of the Coronado fault. A subsequent trench by CCA-Southland (D.Carroll, 1999, personal communication) found unfaulted late-Quaternary sediments across the projection of this inferred fault. The middle anomaly may be a result of facies changes or erosion, but is nevertheless a deeper feature that was not traceable above a late-Pleistocene marine sand ("E" sand). The eastern anomaly was indicated by lack of continuity of some distinctive horizons and was on trend (established later) with the fault identified to the north by Leighton (1979).

The inferred fault associated with the eastern anomaly was first exposed in two trenches, south of Broadway and east of Front Street (Woodward-Clyde, 1980). The fault was determined to strike N5°W, and dip 60°-80°E, with normal displacement. Secondary shears were present for at least 2' to the west and 6' to the east of the main shear. The main fault offset Pleistocene Bay Point Formation (unit Qbp: 120-180 cm apparent vertical separation), a buried colluvial wedge (Qmw) and an old buried paleosol (unit ${}^{III}B_{2/3}$: 60-120 cm apparent vertical separation)(Figure 5). A younger paleosol (unit ${}^{II}B_2$ in Figure 5) was "estimated to be at least 20,000 years old, based on the degree of soil profile development as compared to soil profile development in other areas of California." The consultants closely examined the irregular base of the ${}^{II}B_2$ paleosol and concluded that the 13-15 cm step above the fault in the south wall of trench 2 was not due to faulting. Other trench exposures of the fault showed a less distinct irregularity.

The fault was also exposed, and first named "San Diego fault", during monitoring of sewer trenching along Broadway, between Front and 1st Streets (Artim and Streiff, 1981; Elder, 1982; Elder-Mills, 1982; Streiff and others, 1982). The sewer-line excavation exposed about 6m of late-Pleistocene-Holocene stratigraphy within an area that has otherwise been covered by development since before the earliest aerial photos. Normal faults were distributed over a zone about 46m wide, with an apparent horst in the western half of the fault zone. Maximum vertical separation was described as 3-4m on middle to late-Pleistocene terrace deposits (equivalent to Qbp of Woodward-Clyde, 1980). A 75-128ka paleosol (equivalent to unit ${}^{III}B_{2/3}$) was displaced a minimum of 60cm. A soil estimated to be at least 20,000 years old (equivalent to unit ${}^{II}B_2$) was unfaulted (Artim and Streiff, 1981). No other faults were logged in this trench (see Figure 4 for sewer trench location).

Additional studies for a reduced, 9-block, Horton Plaza Redevelopment area (Leighton, 1980) identified another possible area of faulting northeast of 1st Avenue and G Street. Based on boring data a possible fault was inferred, with the southwest side displaced down about 5 feet. This was opposite the sense suggested by previous borings (Crandall, 1980). The observed sense of displacement suggests that the inferred fault may be secondary to the main fault to the west. Based on stratigraphic correlation with other studies, secondary faulting (if present) was considered to be older than 20,000 years.

A study just west of this latter locality found the main trace of the San Diego fault during excavation for subterranean parking (ICG, 1990). This location, as well as the inferred faults to the east, probably correlate to the eastern anomaly interpreted by Crandall (1980). The main fault has a strike of N5°-8°W and dips 70°-78°E. As at the localities to the north, the east side was downdropped. The zone of faulting had a width of about 30 feet (10m). Deposits across the fault did not match within the nearly 20'-deep excavation, and the consultants estimated 7-10m vertical displacement of the late-Pleistocene "E" sand (equivalent, in part, to unit Qbp of studies to the north). A paleosol with a ${}^{14}C$ bulk soil date of 13,140 ± 340ybp (possibly equivalent to unit ${}^{III}B_{2/3}$ to the north) was offset an indeterminate amount, but an overlying æolian unit (${}^{14}C$ bulk soil date 2040 ± 90ybp) was not faulted.

The fault was next located in the block to the southeast (Geocon, 1995). Two trenches near the northeast corner of 1st Avenue and Market Street documented a 5m-wide fault zone, with a main break oriented N06°W, 62°E. The base of a young soil, tentatively correlated with the æolian unit at the site to the northwest, was faulted over a width of about 1m. Carbonized wood (detrital) collected from within this soil yielded a ^{14}C date of 5230 ± 60 ybp, but faults were not traceable to this level. The soil was estimated by the consultants to have formed over the last 15,000 years. Therefore, they estimated that faulting was younger than 15,000 years but older than 5230 years. As at the previous site this young unit is thicker to the east of the fault. Vertical separation on a late-Pleistocene unit was estimated to be about 1.3m. Two additional trenches across the remaining width of this block did not expose the faults inferred by the 1980 Horton Plaza study by Leighton, but an observed zone of joints and fractures might represent the southern remnant of such faults, if they exist.

A 15-foot wide fault zone (trending N11°W) was exposed in the next block south (south of Market Street) in three trenches (Kleinfelder, 1998). In this investigation, a displaced krotovina (MRT date of 9,540 ± 50 ybp) provided evidence that the fault had moved in the Holocene. Differences in thickness of some colluvial units across the fault indicated a lateral component of displacement. Furthermore, based on inferred offset of a channel deposit (exposed in trenches), the consultants suggested the lateral component was a minimum of 9' (~3m).

The southernmost exposure of the San Diego fault to date (the northernmost exposure being in the Broadway sewer trench) was in the block south of Island Ave. and west of 2nd Ave. The fault, starting to trend more southeasterly, was exposed in several trenches for an unreleased study by consultants (Werner Landry, personal communication, 1999). No age data were available at the time of this writing.

Studies along the northern projection of the fault (Woodward-Clyde, 1993) as well as observation of the excavation for that project (Werner Landry, personal communication, 1999) found no faulting at that site. This suggests that if the fault extends further north it must veer or step westward.

<u>"Downtown graben" faults</u> (Figure 6)

This zone of faults was identified previously and zoned as a surface rupture hazard (CDMG, 1991) based on data from several independent consultants reports (for a summary of this work see Treiman, 1991 and 1993). The observed faults indicated a structural graben. Subsequent studies have provided evidence that this diffuse zone extends southward (Woodward-Clyde, 1994b; Leighton and Associates, 1998; URS, 2001).

In Woodward-Clyde's (1994b) study along K and L streets, between 12th Avenue and 13th Street (see Figure 6), a zone of faults, up to 3m wide, was observed in three trenches. The fault either bends or steps left as it traverses the site in a northerly direction. Faulting was interpreted to have occurred most recently within the past 300 to 500 years (based on ^{14}C dating of charcoal within a fault-bounded unit). Apparent displacement is down to the east and increases (to as much as 2m) in lower, older deposits.

A study to the northeast, in 14th Street, by Leighton and Associates (1998) found another fault strand, trending N55-60°E and dipping steeply SE, that displaces Holocene alluvium (<3230 ± 40 ybp - age based on soil carbon ^{14}C dating). Apparent separations again indicate a down to the southeast component, but striæ and mullion in the shear zone indicate "predominantly strike-slip movement".

The study by URS (2001), south of Imperial Ave. and east of 16th St., found evidence of significant faulting within the late-Pleistocene Bay Point Formation, with "an apparent vertical separation of approximately 6 feet". The geometry of the faults is similar to other exposures of the eastern margin of the graben. Although no younger sediments were present to confirm the age of faulting, the consultants noted evidence of multiple rupture events and observed that the fault zone contained "very loose brecciated material ... suggesting recent disturbance and little healing of the fault plane". They felt that some fissure filling may have been derived from younger deposits and also noted the coincidence of a topographic break-in-slope with the fault.

To the northwest of the graben and the Alquist-Priolo zone, a recent study has located another fault with similar geometry to the graben faults (Figure 6). However, the youngest material displaced was Pleistocene Linda Vista Formation, and Holocene activity could not be established (Kleinfelder, 1998).

Silver Strand fault (Figure 7)

The Silver Strand fault was named by Kennedy and Welday (1980) and extends from the Mexican border (offshore) northward across the Silver Strand and into San Diego Bay (Figure 2). In a summary of previous work Treiman (1993) wrote: "*The Silver Strand fault consists of two close strands for several kilometers south of the Silver Strand and then continues south as one relatively continuous fault for a total distance of more than 12 km, from Glorietta Bay to the area offshore from Imperial Beach. Additional short, en echelon fault segments suggest that this fault may extend to the international border.*".

A recent investigation of faults underlying the Coronado Bridge (Kennedy and Clarke, 1999a,b) has better defined this fault within San Diego Bay, showing it to consist (in the bay) of a northeast-trending zone of several faults; the main fault being double-stranded (strands A1 and A2, see Figure 7). The faults show normal displacement and mostly dip to the southeast (50°-55°), although some secondary faults (A3, B1, B2 and B3) dip to the northwest, delineating a graben structure. The submarine faults in San Diego Bay displace sediments dated at 4435±115 ybp (^{14}C) and some strands clearly fault younger, but undated, sediments (Kennedy and Clarke, 1999b). Faults A1 and A2 project across land and are among those identified as displacing Holocene sediment. Submarine faults A3, B1, B2, B3 and C1 also displace Holocene sediment and project northeast toward the downtown graben (as do faults A1 and A2). The faults of this zone form the western margin of a broader structural basin termed the San Diego graben.

Coronado fault (Figure 7)

The Coronado fault, named by Kennedy and Welday (1980), is identified in high-resolution acoustic-reflection lines, both in San Diego Bay and south of Coronado, for a total length of as much as 10 to 11 km (Kennedy and Welday, 1980; see Figure 2). In that study the fault was considered to be best defined south of Coronado where it consists of two closely parallel fault strands. Recent work by Kennedy and Clarke (1999a) found the fault within San Diego Bay to be southeast-dipping to nearly vertical, shallowing to ~75°E at depth. The imaged fault, based on single-channel geopulse and multi-channel airgun tracklines, displaces sediments "at or very near the bay floor . . . and is considered to be one of the most youthful faults in this part of the Rose Canyon Fault Zone" (Kennedy and Clarke, 1999a, p.15). Although sediments adjacent to this fault were not directly dated, the fault is traceable into sediments at least as shallow (and presumably as young) as those displaced by the Silver Strand fault.

Possible onshore topographic expression of this fault across Coronado (Kennedy, Welday and others, 1977) was investigated by Artim and Streiff (1981). In their 200' trench down the slope and past the base of a gentle topographic escarpment (see Figure 7 for escarpment and trench location) Artim and Streiff did not observe any evidence of faulting or deformation in presumed middle to late Pleistocene laminated to moderately-bedded marine deposits. They interpreted the evident escarpment as erosional. A buried paleosol was observed on top of the eroded marine deposits east of the toe of the escarpment, and estimated by Artim and Streiff (1981) to be 10,000 years old, based on the degree of soil development (poor to moderately developed structure with thin clay skins and manganese staining along the base). The age of this lower surface would constrain the age of the escarpment.

The position of the apparent scarp relative to the fault in San Diego Bay implies a small left-step north of Coronado. A suggestion of a north-northeasterly continuation of the fault to the vicinity of G and State Street (Treiman, 1993) has been partially refuted by recent work by CCA-Southland, at least within the latest Pleistocene and Holocene section (D. Carroll, personal communication, 1999, see Figure 4 for location).

Spanish Bight fault (Figure 9)

The Spanish Bight fault was named by Kennedy and Welday (1980). It is "one of the most conspicuous faults mapped in San Diego Bay" and extends south for about 13km from the Old Town area where it appears to splay from the Rose Canyon fault zone (Kennedy and Clarke, 1999a; see Figure 2). The fault is believed to have been a controlling factor in the formation of the (now filled in) Spanish Bight (Figure 8) and is also conspicuous in sub-bottom seismic profiles south from North Island (Kennedy and Welday, 1980). Crane (1977) plotted faults farther south in the offshore area that appear to extend the Spanish Bight fault to a total of 23 km, with additional short fault segments continuing southward, en echelon, to the international border.

Based on recent marine geophysical surveys in San Diego Bay, Kennedy and Clarke (1999a) observe that the fault dips 75°E, extends to within 5-10 milliseconds of the bay floor, and can be followed continuously as a single break from Harbor Island to North Island (Figure 9). Investigations by Woodward-Clyde (1994a) and URS (1998) for the Navy found the fault to have a flower structure in the upper sediments, with the faults coalescing downward into a southeast-dipping main fault. Although normal separations were detected, the fault pattern suggested to the consultants that strike-slip displacement was also involved. Many strands appeared to be Holocene based on their displacement of sediments within a few feet of the sea-floor and their being overlain only by sediments from 1220-1670 AD (based on dendro-corrected ^{14}C dates); some faults may even have sea-floor expression (Woodward-Clyde, 1994a).

AERIAL PHOTO AND MAP INTERPRETATION

Only minimal aerial photo interpretation was attempted for this follow-up study due to the amount of development extant in even the earliest imagery. Three photos of the downtown area from 1928-29 were inspected to interpret geomorphic evidence of the downtown graben. A hint of the original ground surface was only preserved in the street grades and on a few marginally developed lots.

In general the topographic surveys of the city are more useful than the aerial photography for interpretive purposes. Topographic contours from a 1954 survey (San Diego, 1954) show a south-southeast trending drainage that may be partly fault controlled by the San Diego fault (Figure 10). Visible to the east, in photos, topographic surveys and field reconnaissance, is a broad swale that appears to be associated with the Downtown graben (Figure 11). In its more southeastern extent the graben has locally captured and deflected the otherwise southwest flowing drainage of Powderhouse Canyon (also shown on later maps as Powerhouse Canyon). The left sense of deflection is probably controlled more by the internal gradient of the graben than by any lateral offset. Late Holocene flooding of this drainage has most likely modified or obliterated any fault scarps that may have existed in this portion, but the general location of the deflected portion of the drainage indicates where the structural zone must lie. The south-southwest trending topographic trough still evident today from Market to “L” streets (Figure 6) may be merely part of the erosional channel although locally observed Holocene faults may indicate fault control here, as well.

On North Island/Coronado the Coronado and Spanish Bight faults both seem to be topographically expressed. A gentle east-facing 4-5m escarpment across Coronado Island (Figure 7) appears to be associated with the fault named for that locality. The inferred scarp is steeper to the south (~10-15° as measured from the 7.5-minute Point Loma quadrangle), flattening to around 5° in its middle portion and is relatively broad and subdued at its northern end (still on Coronado Island). The gentle slope suggests that if this feature is of fault origin, it has been erosionally modified. This process might occur readily in the friable sand and silty fine sand described at this locality by Artim and Streiff (1981). The more subdued expression to the north and slight misalignment with the faults mapped in San Diego Bay suggest a possible left-step to the San Diego Bay portion of this fault. To the west an embayment called “Spanish Bight” originally separated Coronado Island from North Island. The embayment was filled in 1944 but is evident in earlier topographic maps (Figure 8). Its more linear west margin was apparently controlled by its namesake fault, and the entire embayment may relate to the apparent left step in the faults north and south of the island.

GRAVITY SURVEYS

Marshall (1989) compiled and discussed numerous gravity surveys done by his students and others in the San Diego area. From the data he interprets San Diego Bay to be underlain by a nested graben trending N10°W. The graben is inferred to relate to a right step-over from the Rose Canyon fault on the north to, perhaps, the Vallecitos-San Miguel fault to the south. The general nature of the graben is also corroborated by gravity studies cited by Kennedy and Clarke (1999a).

A more recent micro-gravity survey by Scott (1994) found evidence to support several elements of the previously inferred “downtown graben”. However, Scott also felt that his data (see Figure 6) provided no support for the “PATC” fault to be the eastern margin of the graben. What his data did suggest is that the western boundary of the graben steps left, with some overlap of faults; as the PATC fault diminishes to the south, the Jerome’s warehouse fault appears to continue with greater geophysical expression.

SEISMICITY

Historical earthquakes in the San Diego area have been fairly limited (Figure 12a).

Nevertheless, there have been several significant clusters of seismicity that may be related to the faults addressed in this FER. These occurred in 1964, 1985, 1986 and 1987 (Simons, 1979; Reichle, Bodin and Brune, 1985; Magistrale, 1993). The 1964 events occurred in southern San Diego Bay (focal mechanism data have not been published). Focal plane solutions for the 1985 events indicated strike slip-displacement, and were interpreted to be associated with right-lateral movement parallel to the mapped faults in the bay (Reichle, Bodin and Brune, 1985). Magistrale (1993) re-interpreted the 1985 events and also looked at the 1986 and 1987 San Diego Bay earthquake clusters. He noted that for the 1985 events the conjugate focal planes (NE-SW) were more consistent in dip and were aligned with the cluster distribution. He suggested that a NE-trending left-oblique fault was a better fit to the data than the originally interpreted fault plane. Following the same reasons, Magistrale (1993) felt that the 1986 and 1987 earthquakes similarly suggested a NE-SW trending left-oblique faulting mechanism (Figure 12b).

DISCUSSION AND CONCLUSIONS

All of the faults under consideration here seem to be part of the trans-tensional zone at the southern end of the Rose Canyon fault zone. This zone has been suggested to be part of a rhombochasm between the Rose Canyon fault zone to the north and perhaps the Vallecitos fault zone to the south (Marshall, 1989; Treiman, 1984 & 1993). The documented Holocene activity of some of these faults, along with historic seismicity, supports the activity of the zone itself, and by inference the likely activity of other major faults within this zone for which there is not yet evidence of activity. Holocene activity of the faults at the extreme margins of the zone (the Point Loma and La Nacion faults) has not been suggested by any investigations that have come to light (Kahle, 1988; Saul, 1979bc).

San Diego fault

The San Diego fault has been clearly defined by a series of geotechnical investigations. Its Holocene activity has been demonstrated by one study (Kleinfelder, 1998) and strongly indicated by two other recent studies (IGC, 1990; Geocon, 1995) where a young alluvial/soil unit thickens across the fault. At the IGC (1990) site the apparently unfaulted 4-5ka alluvium appears in the trench log as if it may have been deposited across a degraded fault scarp at least 15cm high. A Holocene age of faulting is also well within the data constraints at the Geocon (1995) study site.

Although studies at the fault's northern end (Woodward-Clyde, 1980; Artim and Streiff, 1981) appeared to argue against Holocene displacement, a review of the trench logs suggests that this conclusion may no longer be justified. Figure 5, for example, shows thickening of the ${}^{II}B_2$ soil that may be due to faulting. This soil was estimated to be 20+ka but might be younger, considering the relatively rapid soil development in the coastal environment. Supporting a younger age is the correlation, made by ICG (1990) of their ~13ka unit 2 with unit S_3 (equivalent to soil ${}^{III}B_{2/3}$) to the north which underlies (and is therefore older than) soil ${}^{II}B_2$. A narrow channel above the fault may be an in-filled fissure related to slight fault displacement. Repeated Quaternary displacement at this site is indicated by the buried colluvial wedge (unit Qmw) also identified by Woodward-Clyde (1980).

The fault (or associated surface deformation) may also have controlled the location of a gentle drainage swale (now masked by development) that trended southeasterly (Figure 10). A left-deflection of the drainage in the vicinity of Island St. may indicate a similar left-step in the fault, although no evidence has yet arisen to support this speculation.

Downtown graben faults

The Downtown graben is clearly indicated as a structural zone in the earlier work that was the basis for Alquist-Priolo zoning in 1991. Extension to the south (as far as K Street) of at least the western margin of this structural zone, as well as Holocene activity, has been corroborated by recent geotechnical studies (Woodward-Clyde, 1994b; Leighton and Associates, 1998). A micro-gravity study (Scott, 1994) also seems to corroborate the western structural margin, as well as clarify the probable left-stepping nature of the faults that was only hinted at by previous exposures. Analysis of drainage patterns further indicates that the graben structure extends south-southeast to at least the vicinity of Island Ave. A continuation of the eastern margin of the graben is indicated by the URS (2001) study, and the recency of activity is suggested by observations in their trench as well as the association of the fault with topographic relief. This latter study, along with the similarity of age and geometry between the downtown graben and the Silver Strand faults, strongly suggest a connection between these two extensional zones.

The short fault segment identified by Kleinfelder (1998) to the northwest of the graben is not clearly related to this structure and may be an older element. In addition to no evidence of post-Pleistocene displacement it is not associated with any of the topographic expression that is linked to the active graben and would require a left-step of ~300 m to relate the two faults.

Silver Strand fault

The Silver Strand fault zone is in the unusual situation of being better defined offshore than onshore. However, the interpolations that must be made across the Silver Strand (spit) are not unreasonable in light of the well-constrained Holocene activity and location in San Diego Bay. The active fault strands that project onshore (to the south) are faults A1, A2 and C1. Fault C1 lines up with and is here inferred to connect with another fault strand to the south that has similar age and expression. This inference is based on sense of offset, orientation and shallowness of offset (Figures 12 and 14 in Kennedy and Clarke, 1999a).

The structural graben identified by the work of Kennedy and Clarke (1999a,b) between faults A1 and A2 on the west and the B faults on the east appears to project onshore again to the northeast.

Coronado fault

Like the Silver Strand fault, the Coronado fault is well defined in the marine environment (Kennedy and Welday, 1980; Kennedy and Clarke, 1999a). However, there is also possible geomorphic evidence for this fault onshore. A linear east-facing escarpment that lies across the City of Coronado is aligned with the fault to the south and, with a small left step, to the fault as identified in San Diego Bay. Although a study by Artim and Streiff (1981) did not find this fault in a trench across the escarpment, the marine seismic data make it difficult to **not** interpret a fault through Coronado. Since these faults have a strong normal component it may be that the fault is buried beneath slopewash and lies to the east of the current toe of slope. A slight concavity of the scarp line at the trench locality along with the friable nature of the exposed sediments also suggests that the slope may have retreated slightly westward at this point. Although the age of the retreated scarp might be constrained by the age of the buried paleosol under the lower surface to the east (Artim and Streiff, 1981), there was no dateable material found and other factors make it possible that a scarp was formed and erosionally altered in considerably less time than the 10,000 years estimated by Artim and Streiff (1981). The apparent age of the paleosol (as interpreted from the degree of soil development) may have been partly due to inherited characteristics from cemented layers within the marine deposits and the relatively high mobility of clay in soils in the coastal environment. I would hesitate to deny the onshore presence of this fault based on one trench. Although faulted offshore sediments were not specifically dated, Holocene activity of the offshore fault is strongly indicated by its shallow expression in seismic profiles (comparable to the age-controlled section displaced by the Silver Strand fault), as well as the location of the fault within the broader structural graben.

Spanish Bight fault

The Spanish Bight fault is generally accepted as the controlling structure for the old Spanish Bight and is positively identified by marine seismic studies in the bay and to the south (Kennedy and others, 1977; Kennedy and Welday, 1980; Woodward-Clyde, 1994a; URS, 1998; Kennedy and Clarke, 1999a). Holocene activity is interpreted by Woodward-Clyde (1994a) and URS (1998) based on proximity of fault rupture to the bay floor. This interpretation is consistent with data from Kennedy and Clarke (1999a,b) who found the fault extending to shallow depths equivalent (but not necessarily correlative) to Holocene age deposits at the Coronado bridge. The shape of the former Spanish Bight (Figure 8) suggests control by faults, along both margins, which would be northern extensions of the faults mapped to the south by Kennedy and Welday (1980). This appears to be part of a left-step, the eastern strand of which dies out before reaching San Diego Bay.

RECOMMENDATIONS (Figure 13)

San Diego fault

The San Diego fault is sufficiently active and well-defined and should be zoned for its entire identified length. Fault location is based on geotechnical studies indicated on Figure 4. Holocene activity is based on studies by Geocon (1995) and Kleinfelder (1998).

"Downtown Graben"

The individual faults that comprise the San Diego graben may not yet be entirely identified, but this zone of probably discontinuous faults appears to extend southward. The presently established Alquist-Priolo zone on the Point Loma quadrangle should be extended southward to encompass the identified faults (Leighton,1998 and Woodward-Clyde, 1994; URS, 2001) as well as the remainder of the structural trough indicated geomorphically and by gravity survey (Figure 6). These faults are sufficiently active, and the zone is well-enough constrained that future fault studies have an excellent chance of identifying additional faults within the recommended zone. It is also judged reasonable, based on similar age and expression, to conclude that this zone probably extends to join the Silver Strand and related faults to the southwest.

Silver Strand fault

The Silver Strand fault is sufficiently active and well-defined. Faults A1, A2 and C1 should be zoned where they cross land. Faults A3, B1, B2 and B3 are also Holocene in age and project toward the downtown graben, thus defining a continuous active graben between Coronado and downtown San Diego that should also be zoned. Fault location and evidence for recency are based on Kennedy and Clarke (1999a,b).

Coronado fault

The Coronado fault is sufficiently active and well-defined and should be zoned where it crosses Coronado. Fault location is based on geomorphic analysis for this report and interpolation between well-constrained offshore faults (Kennedy and Welday, 1980 and Kennedy and Clarke, 1999a). Recency is based on similarity of submarine expression with documented Holocene faulting on the Silver Strand fault (Kennedy and Clarke, 1999b).

Spanish Bight fault

The Spanish Bight fault is sufficiently active and well-defined and should be zoned where it crosses North Island and Harbor Island. Fault locations are based on geomorphic analysis for this report and interpolation between well-constrained offshore faults (Kennedy and others, 1977; Kennedy and Welday, 1980; Kennedy and Clarke, 1999a). Recency is based on geomorphic expression (this report and Woodward-Clyde, 1994a), displacement of inferred Holocene sediments (Woodward-Clyde, 1994a and URS, 1998), and similarity of expression in marine geophysical lines with the Silver Strand and Coronado faults (Kennedy and Clarke, 1999a).

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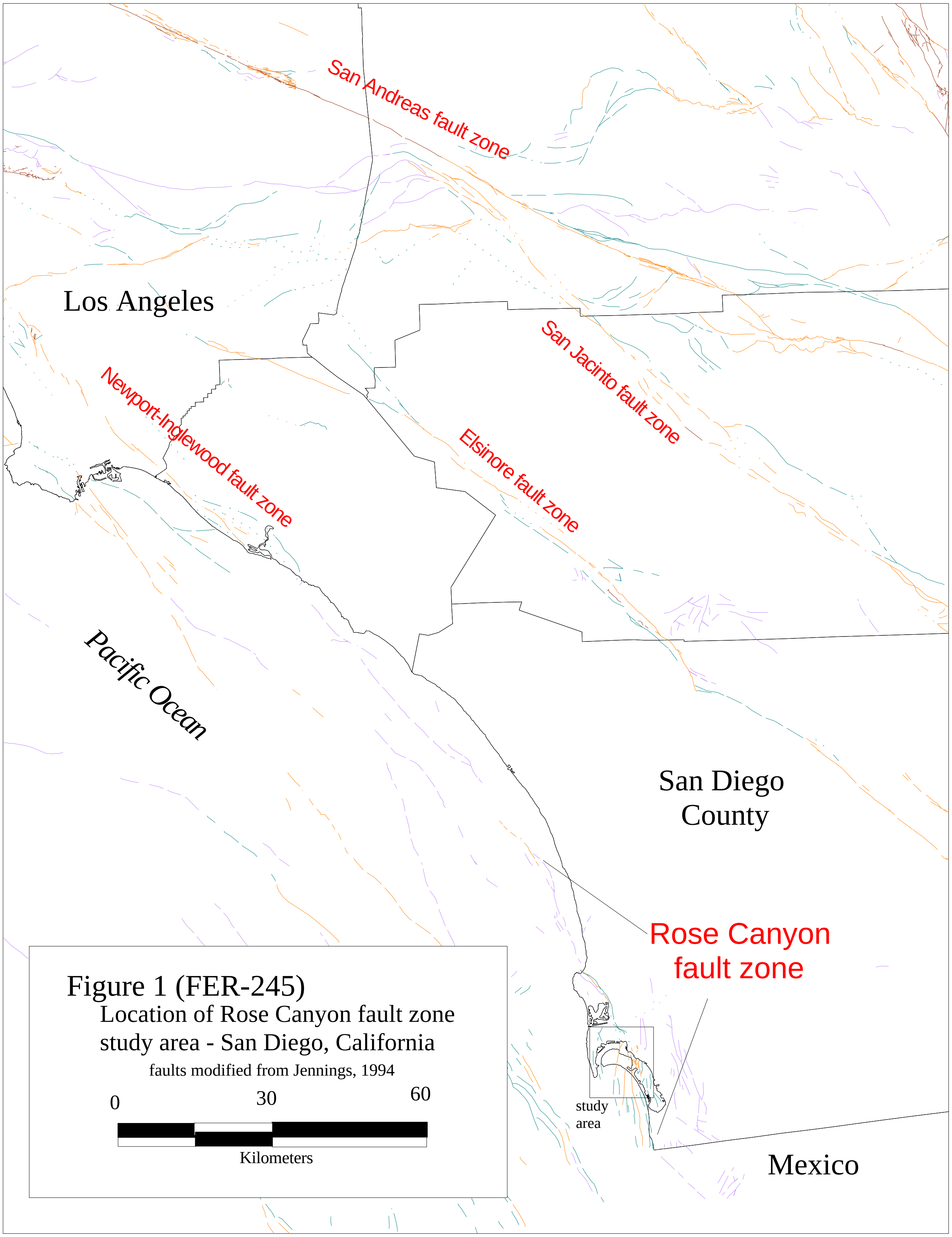


Figure 1 (FER-245)
Location of Rose Canyon fault zone study area - San Diego, California
faults modified from Jennings, 1994

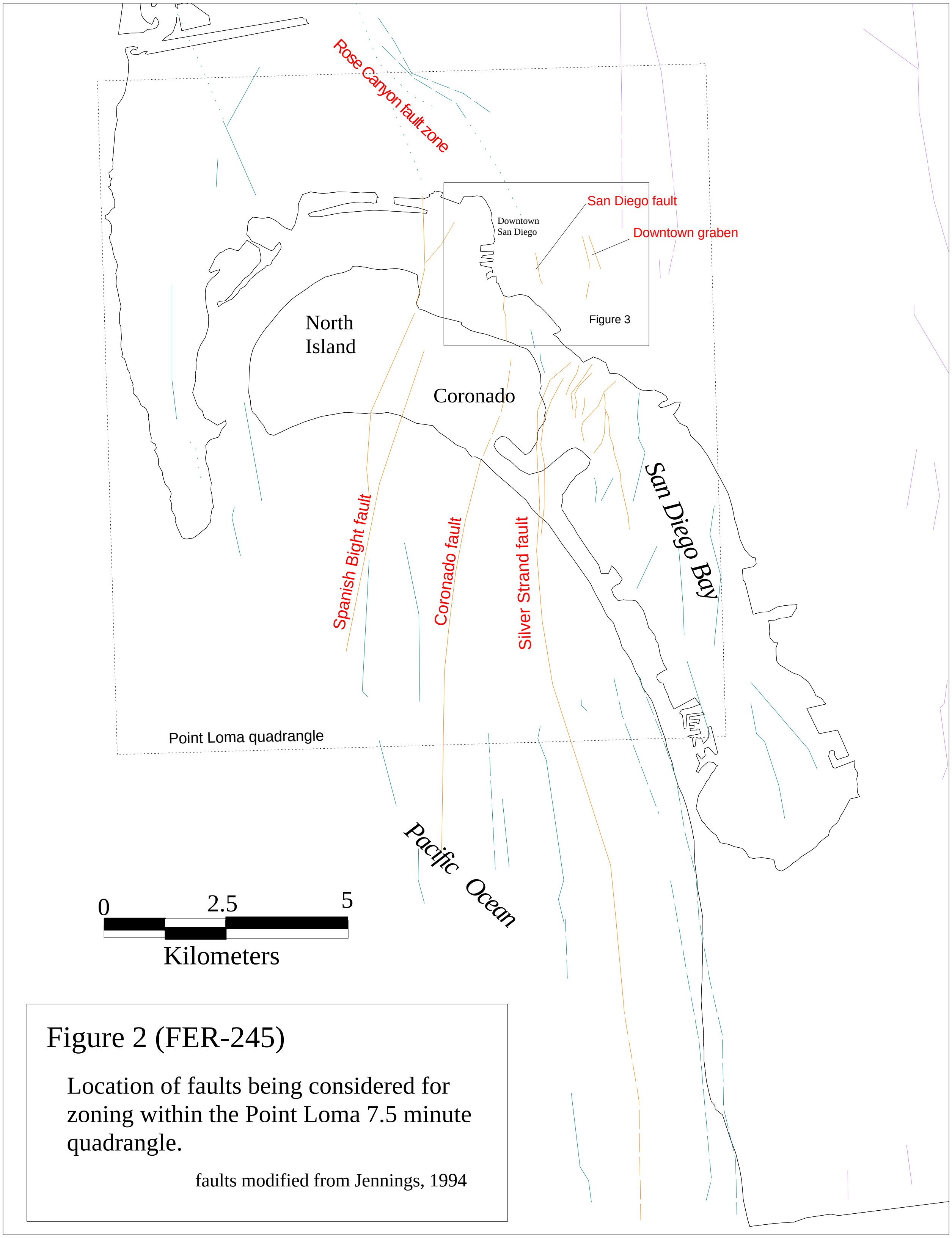


Figure 2 (FER-245)

Location of faults being considered for zoning within the Point Loma 7.5 minute quadrangle.

faults modified from Jennings, 1994

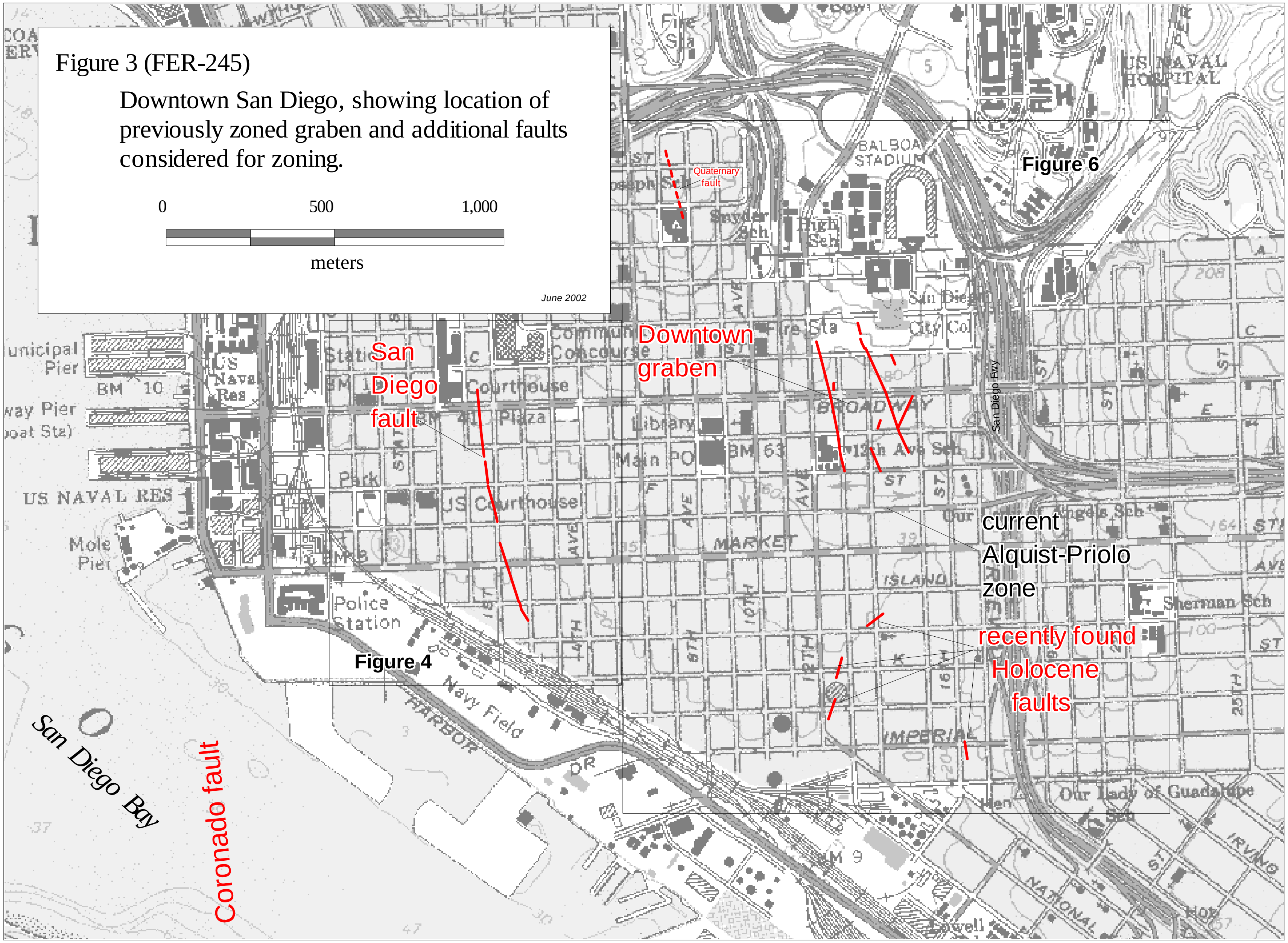


Figure 3 (FER-245)

Downtown San Diego, showing location of previously zoned graben and additional faults considered for zoning.

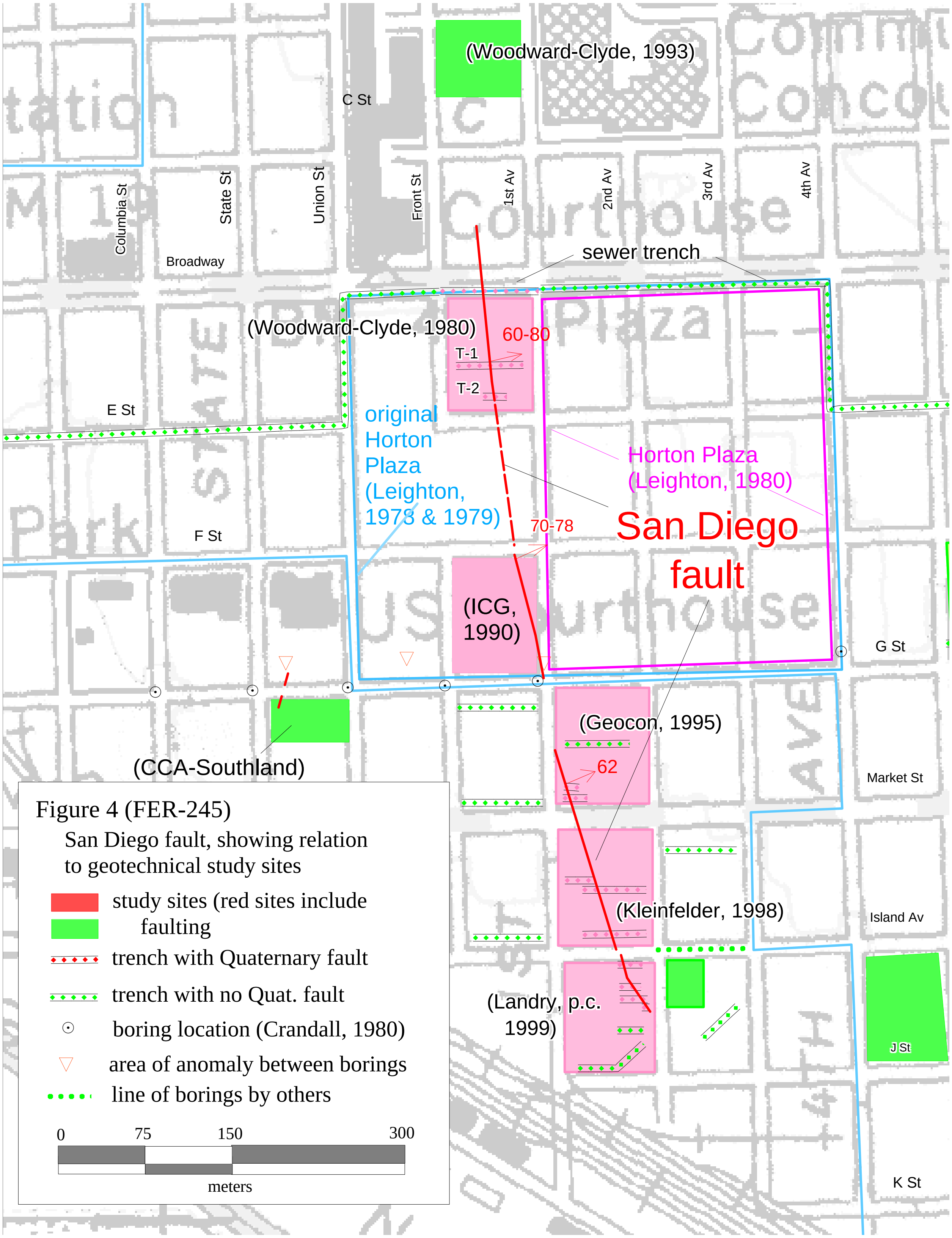


Figure 4 (FER-245)
San Diego fault, showing relation to geotechnical study sites

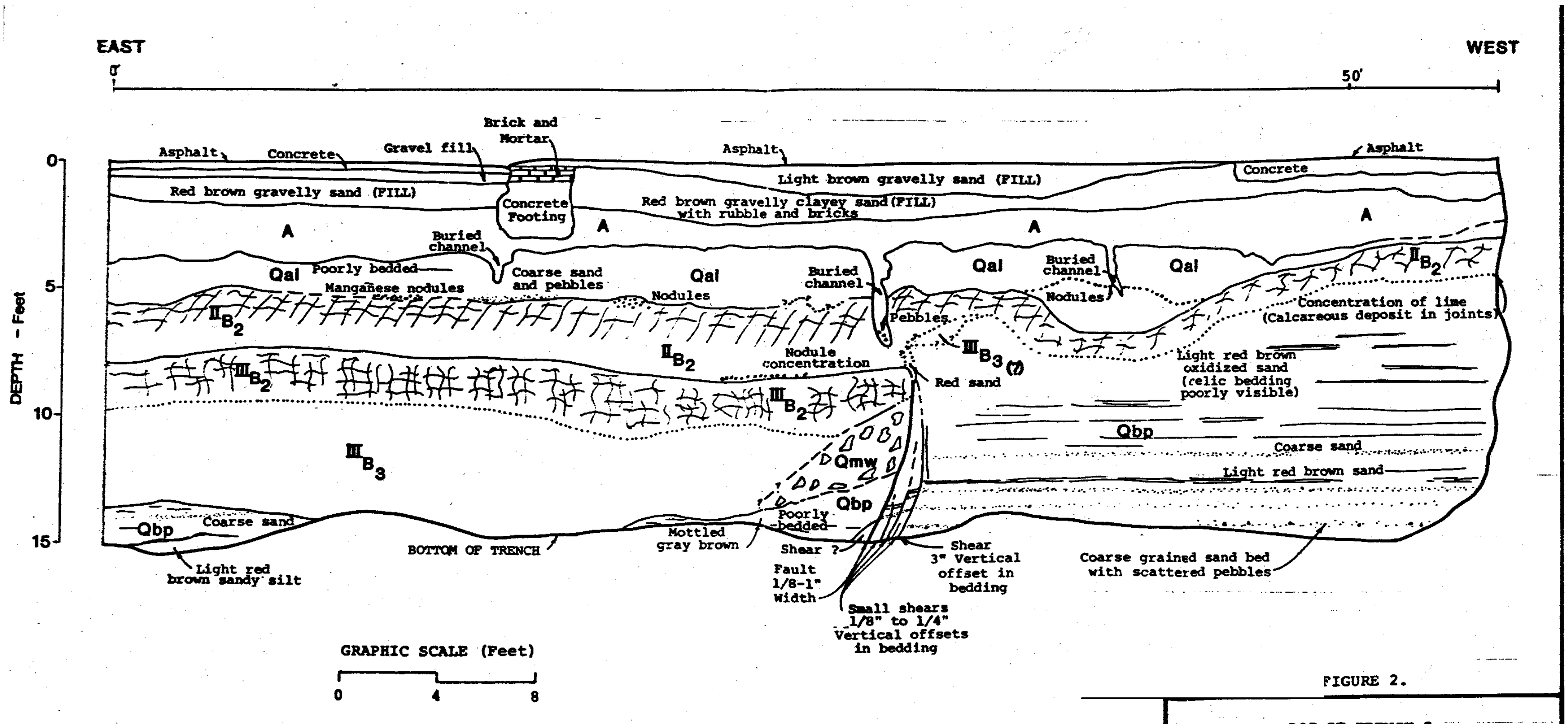


Figure 5 (FER-245)

Log of trench 2 from investigation by Woodward-Clyde (1980) at 1st and Broadway. See text for discussion of exposure.

A- topsoil; Qal- alluvial soil; $^{II}B_2$- buried paleosol; $^{III}B_2$ and $^{III}B_3$- ancient buried paleosol; Qmw- buried talus and weathered scarp soil; Qbp- Bay Point Formation.

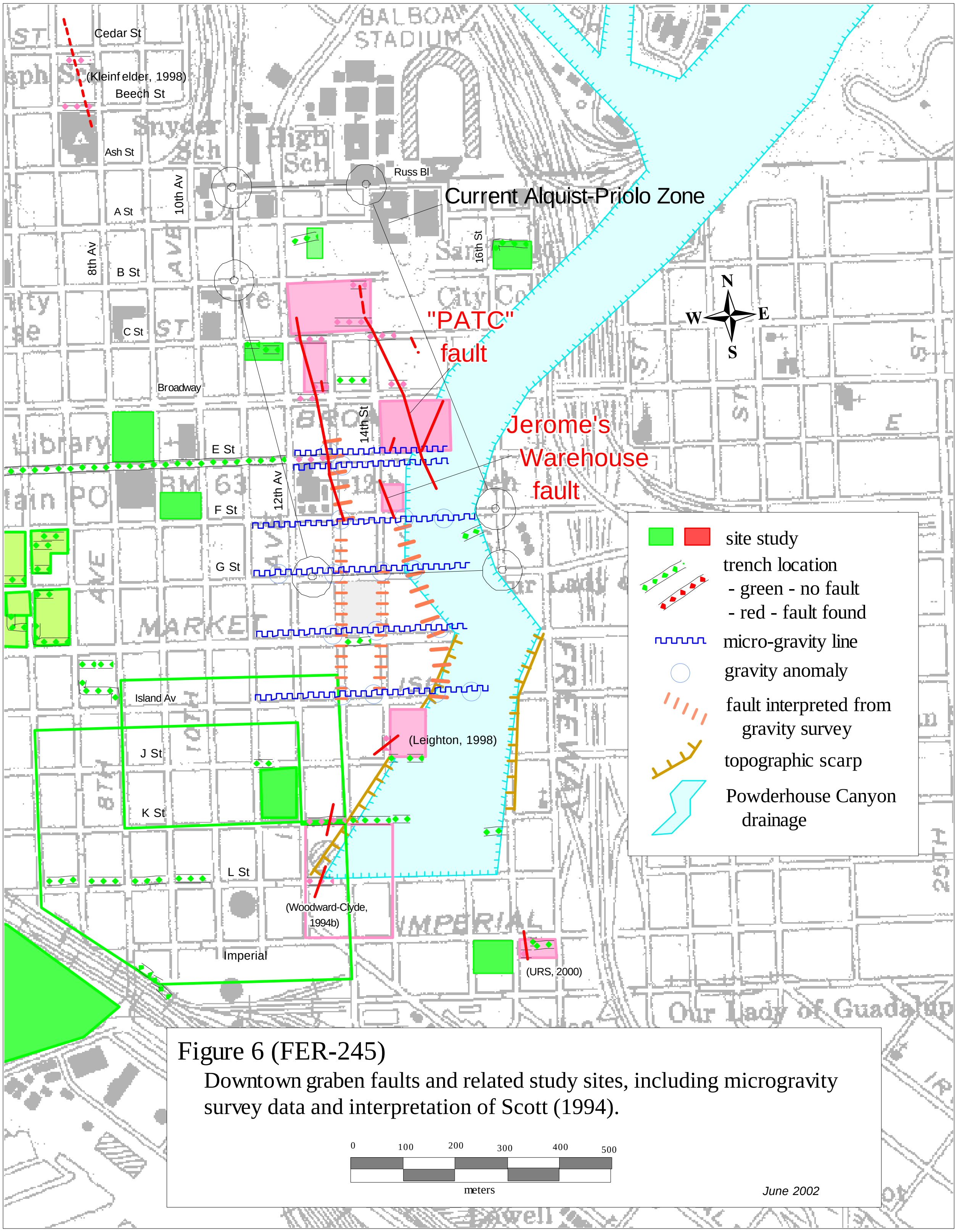


Figure 6 (FER-245)

Downtown graben faults and related study sites, including microgravity survey data and interpretation of Scott (1994).

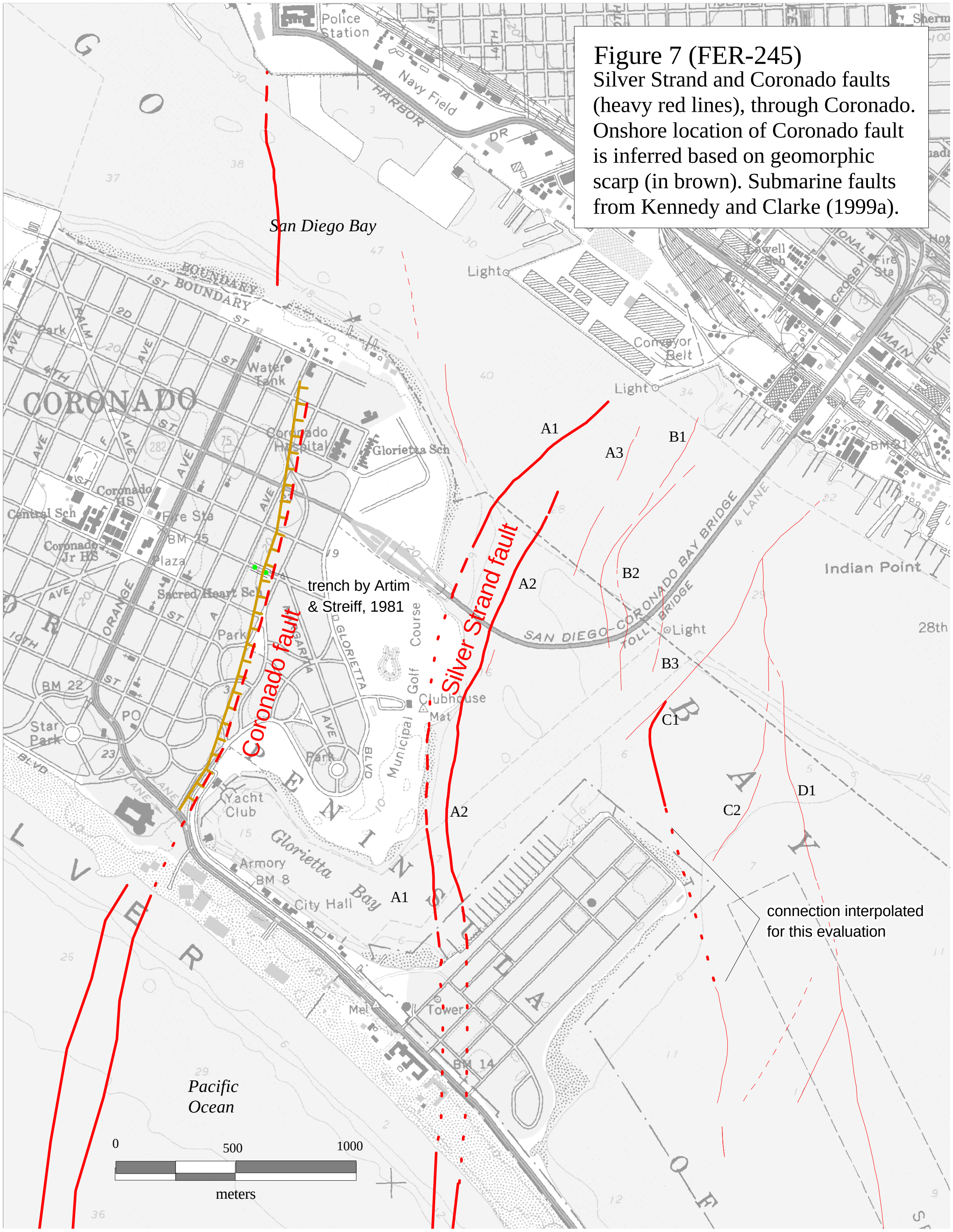
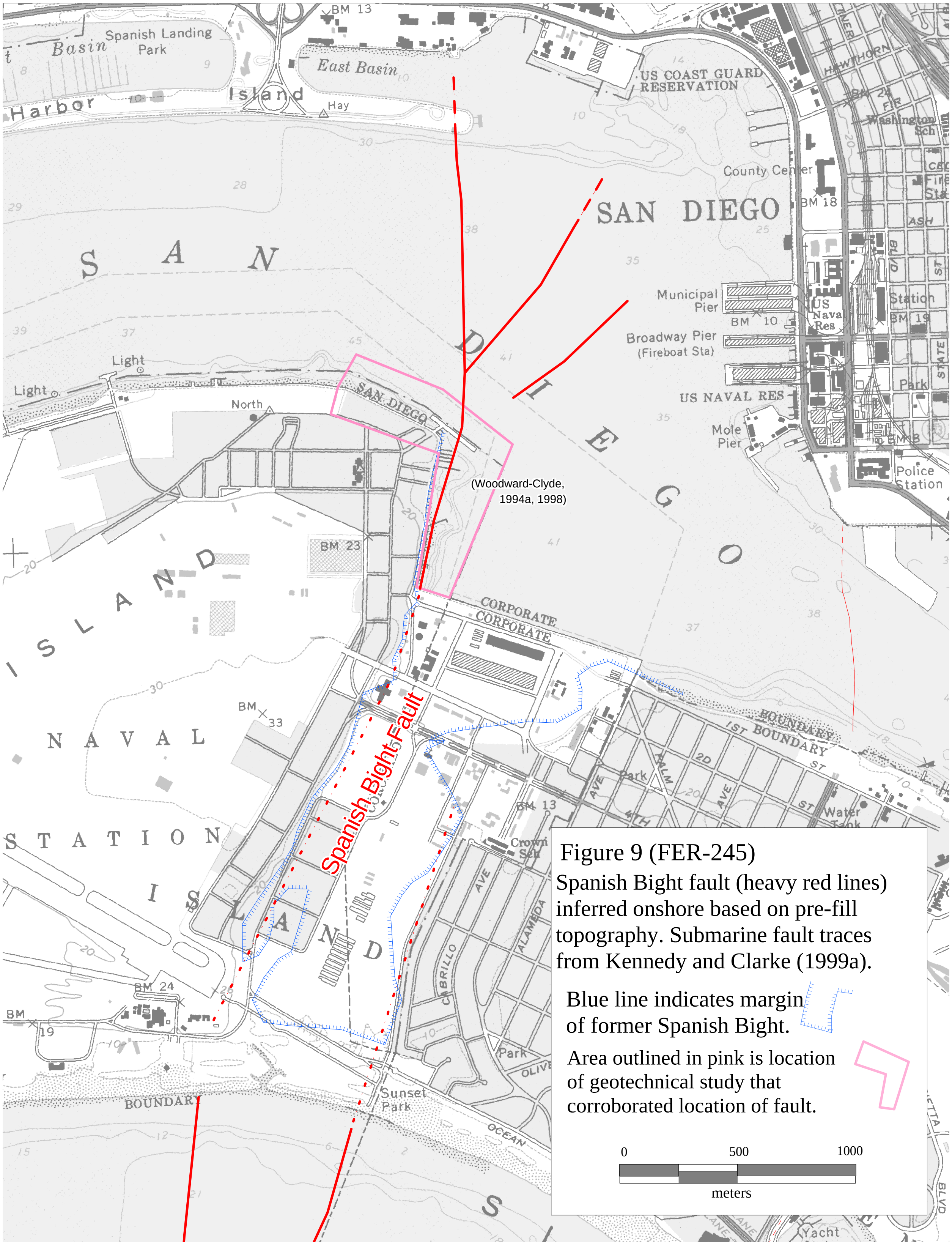


Figure 7 (FER-245)
Silver Strand and Coronado faults (heavy red lines), through Coronado. Onshore location of Coronado fault is inferred based on geomorphic scarp (in brown). Submarine faults from Kennedy and Clarke (1999a).

Figure 8 (FER-245) -- Point Loma quadrangle, edition of 1942,
showing appearance of Spanish Bight prior to filling.
map scale 1:31,680 -- surveyed 1938-39


Spanish Landing Park
East Basin
Harbor Island
US COAST GUARD RESERVATION
County Center
SAN DIEGO
Municipal Pier
Broadway Pier (Fireboat Sta)
US NAVAL RES
Mole Pier
Police Station
SAN DIEGO
(Woodward-Clyde, 1994a, 1998)
NORTH ISLAND NAVAL AIR STATION
CORPORATE
BOUNDARY
Spanish Bight Fault
Sunset Park
OCEAN
Figure 9 (FER-245)
Spanish Bight fault (heavy red lines) inferred onshore based on pre-fill topography. Submarine fault traces from Kennedy and Clarke (1999a).
Blue line indicates margin of former Spanish Bight.
Area outlined in pink is location of geotechnical study that corroborated location of fault.
0
500
1000
meters

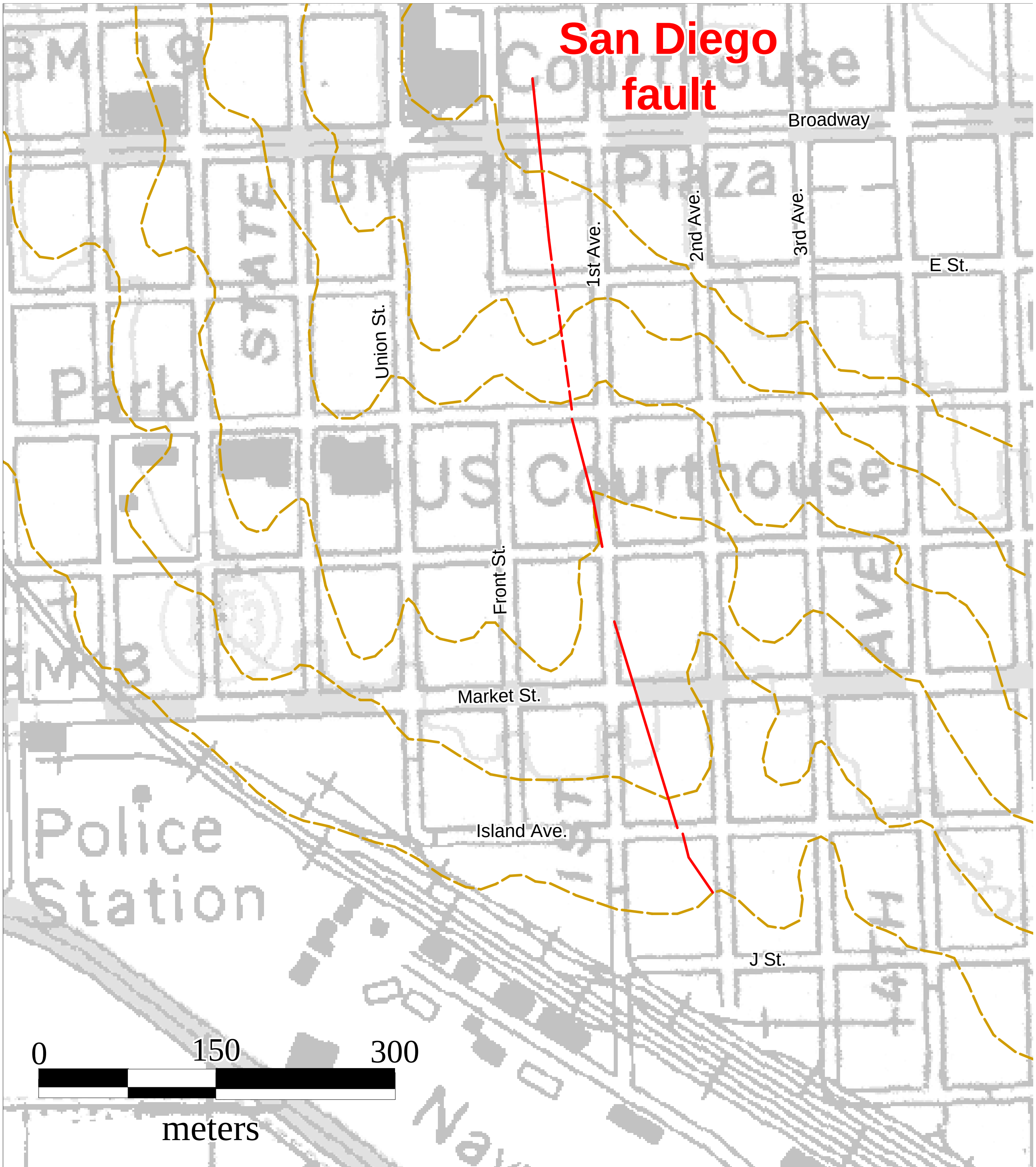


Figure 10 (FER-245)

San Diego fault plotted over 5-foot contours from 1954 City of San Diego topographic survey, showing implied relationship of drainage pattern to the fault. Topography at southern end is suggestive of a left step.

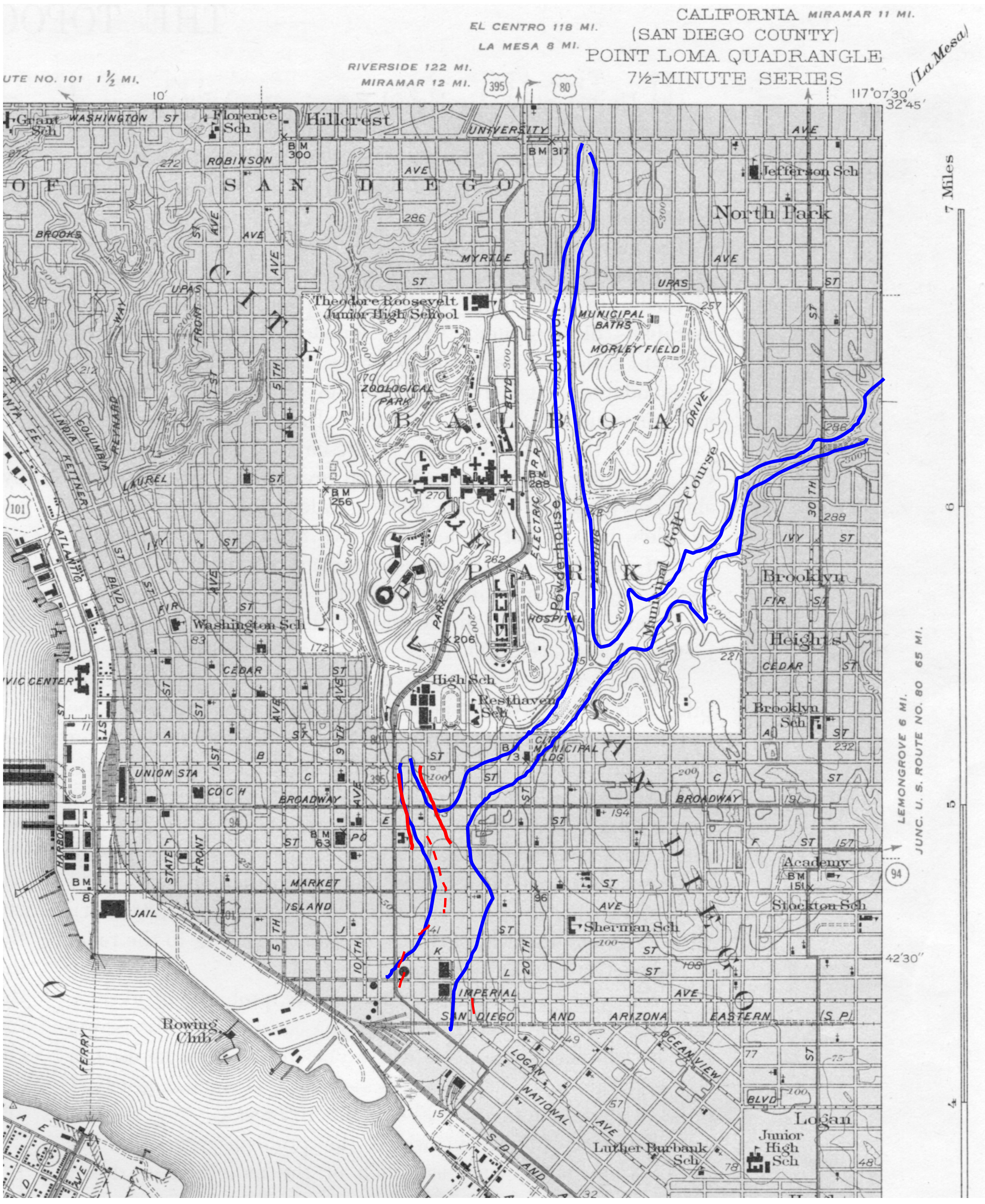
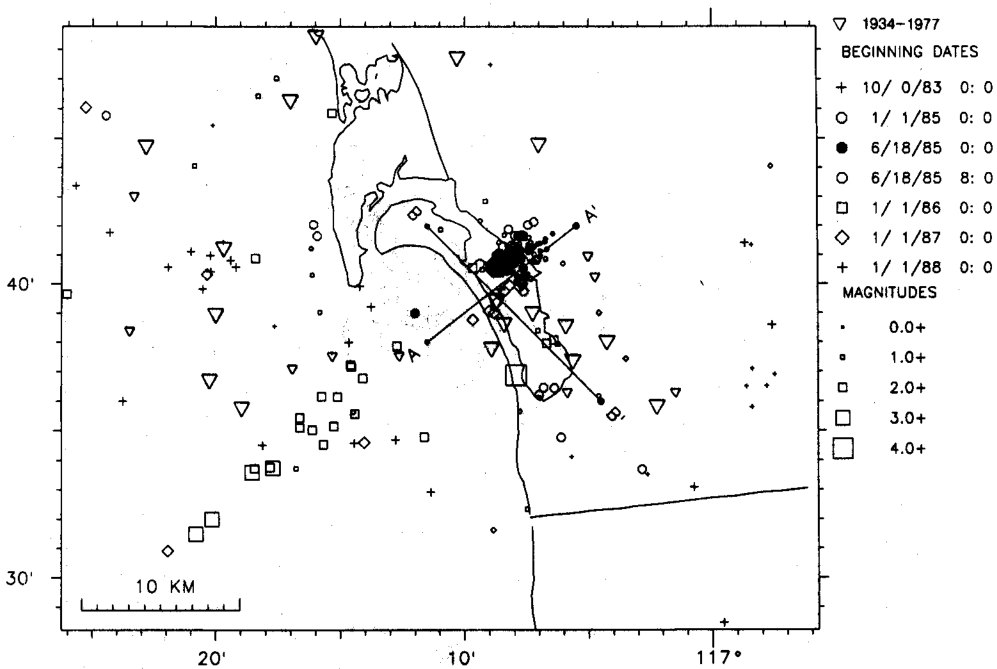


Figure 11 (FER-245)

Drainage pattern on topographic map is emphasized (blue) to show deflection due to inferred influence of downtown graben (faults shown in red). Topographic base is from Point Loma quadrangle (original 1:31,680) surveyed in 1938-39.

(a)



(b)

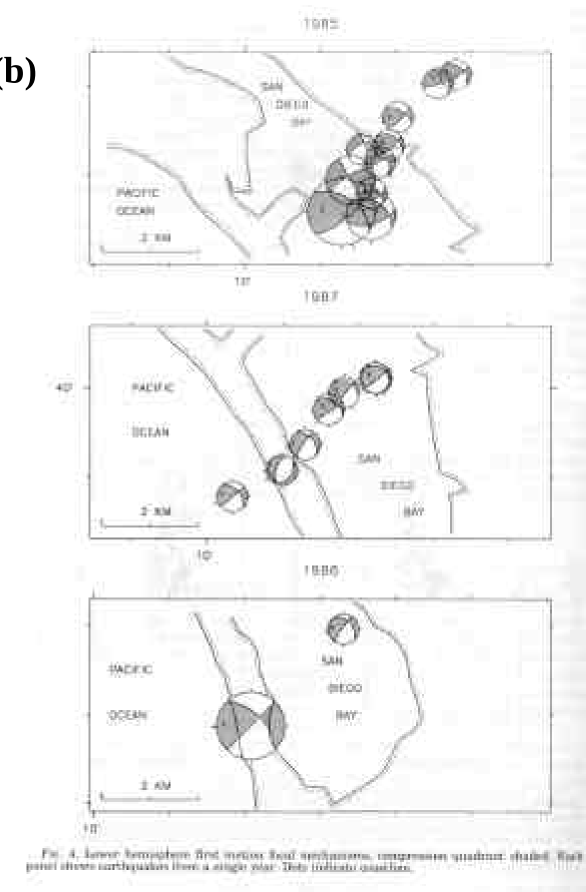


Figure 12 (FER-245)
12a - San Diego area seismicity (1934-1993)
12b – more recent focal mechanisms in San Diego Bay

figures taken from Magistrale (1993)